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FACSIMILE COVER LETTER

To: Examiner Kinkead
Art Unit: 2817

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From: Dennis M. Smid

Date: October 15, 2003

Re: FLH Ref No.: 450117-02808
Serial No: 09/767,124

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Dear Examiner Kinkead:

Pursuant to your request in our telephone discussion today, accompanying this facsimile letter are copies of the two (2) references (i.e. EP 0458452 and GB2324919).

If you have any questions, or if you need anything further, please do not hesitate to contact us.

Best regards,

Dennis M. Smid
Encls.

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(54) Abstract Title

Modulation or frequency conversion by time sharing

(57) A switching signal drives a time-share mixer circuit to alternate between two output signals. The first output signal represents the output of a mixer 123 having a given signal input and a local oscillator signal with a first phase as its local oscillator input. The second output signal represents the output of the mixer having the same input signal and the local oscillator signal with a second phase that differs from the first phase by 90 degrees as its local oscillator input signal. A frequency converter uses the time-share mixer circuit in combination with a switched output phase shifter 209 that switches in sync with the phase of the local oscillator signal to generate a phase shifted output signal in which the time average of an undesired image signal is substantially reduced compared to time average of the desired signal. The phase shifted output signal is then filtered by a filter 205 and amplified as desired by a bandpass amplifier. A clocked inverter in series with one of the mixer ports provides improved performance by eliminating the need for two precisely phase-shifted local oscillator signals.

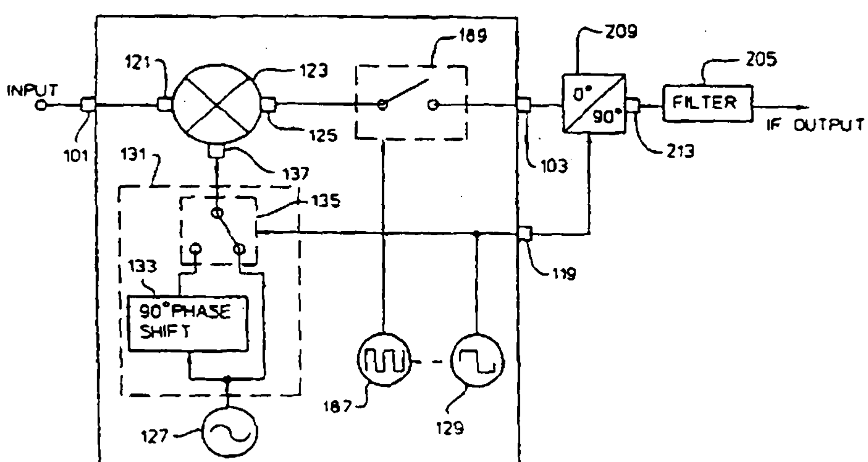

FIG. 13

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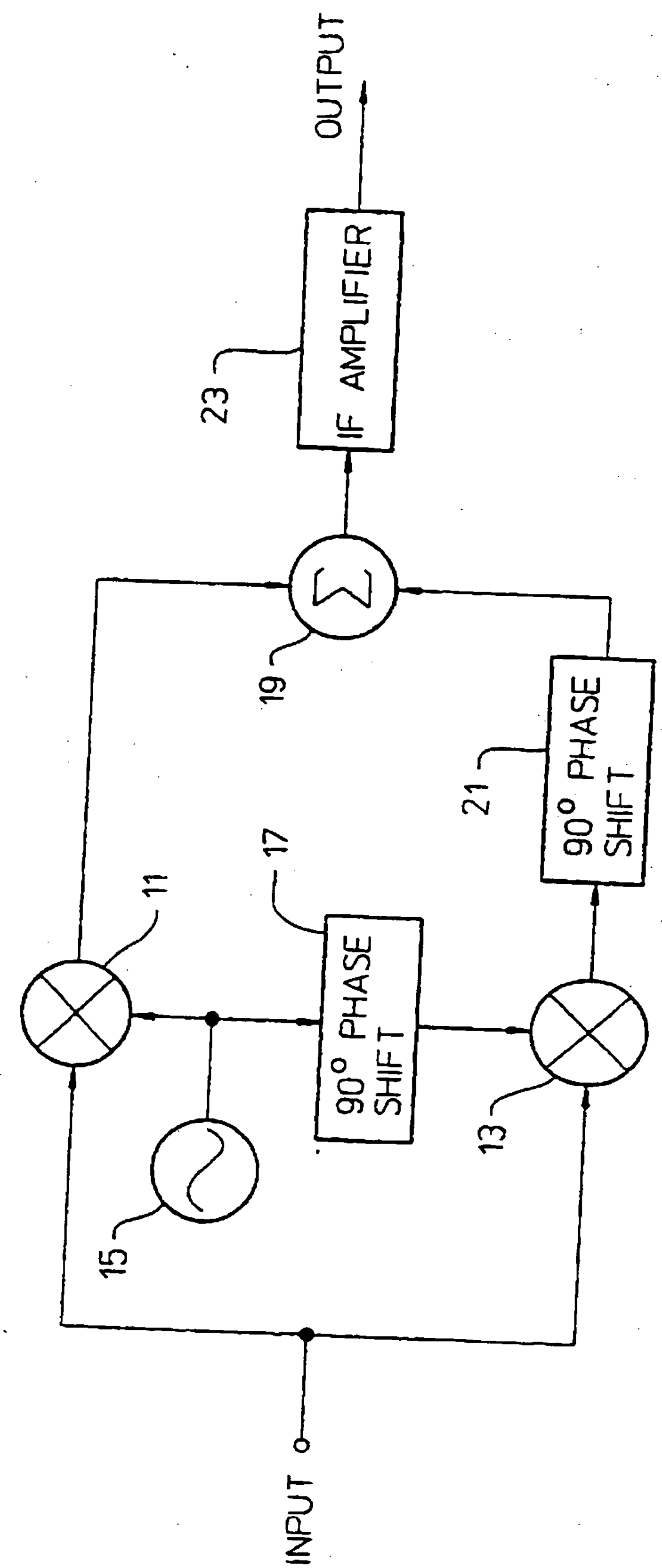


FIG. 1 (PRIOR ART)

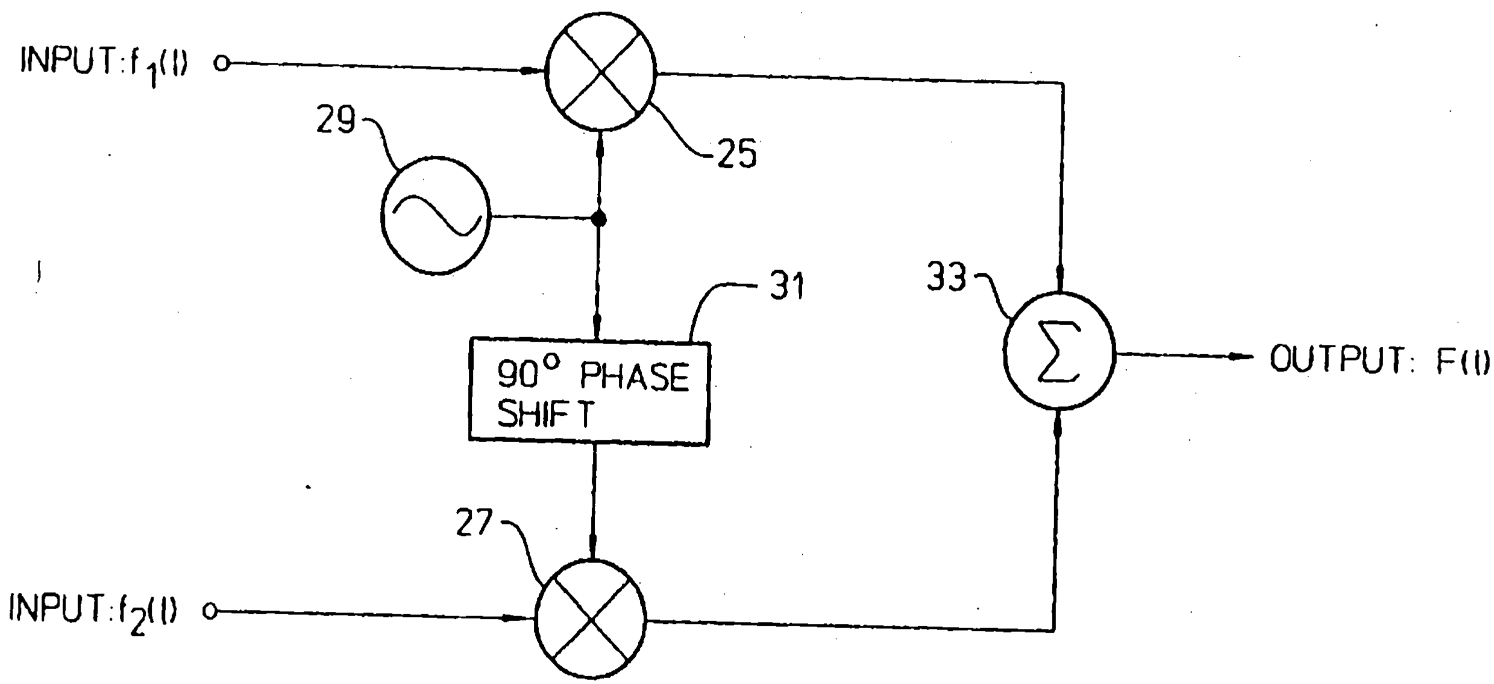


FIG. **2** (PRIOR ART)

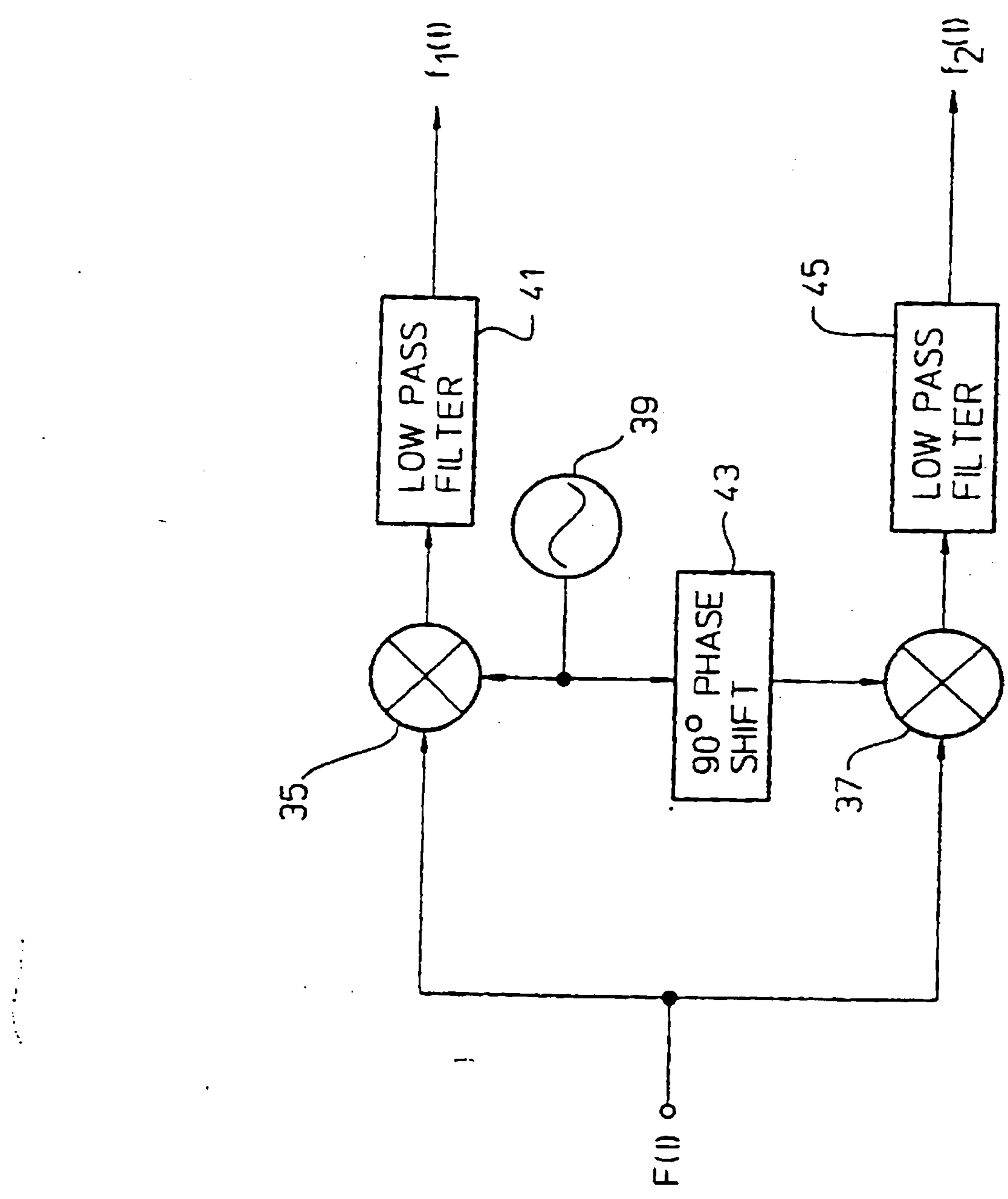


FIG. 3 (PRIOR ART)

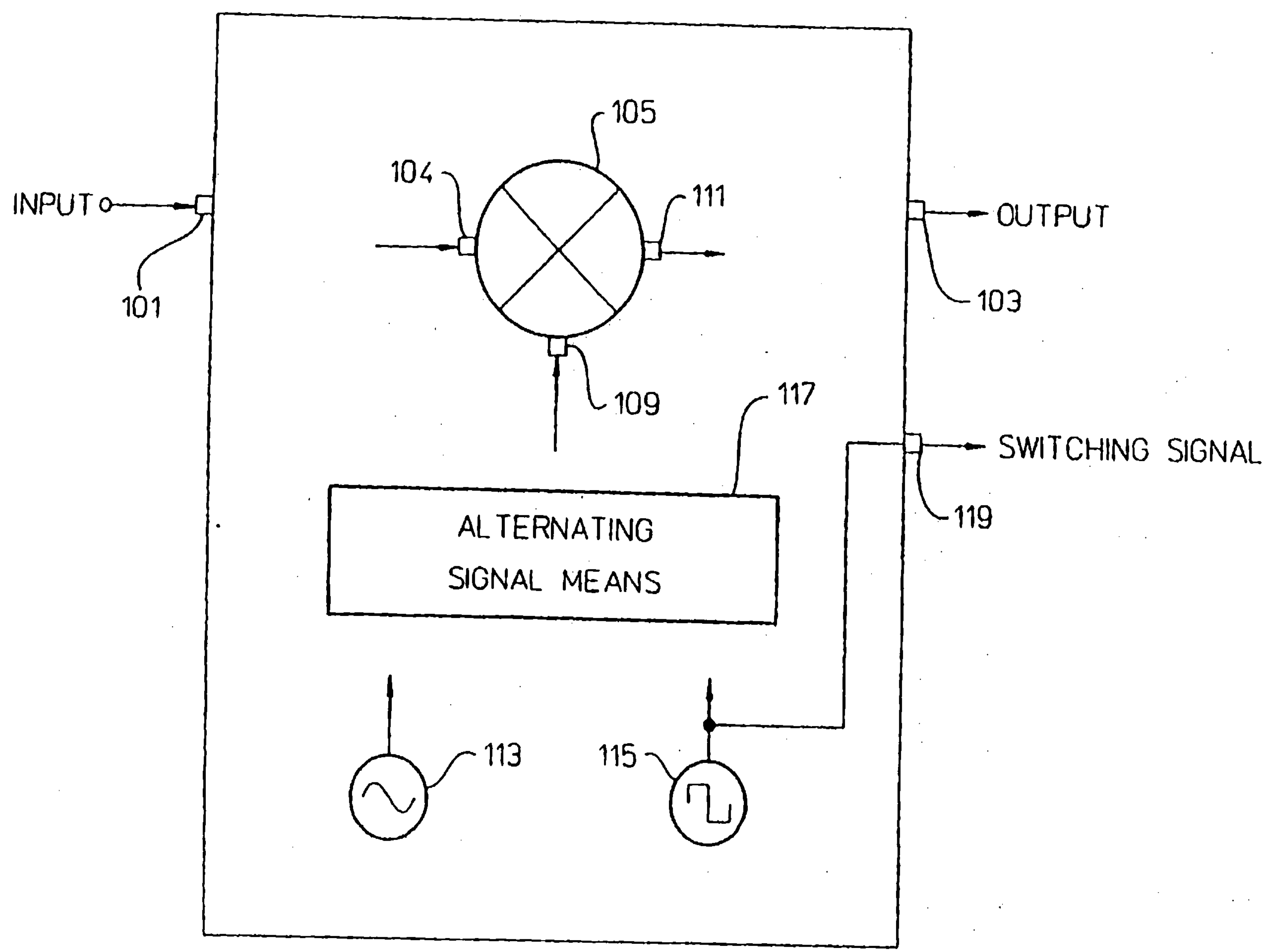

INPUT
101
104
105
111
OUTPUT
103
109
117
SWITCHING SIGNAL
119
ALTERNATING
SIGNAL MEANS
113
115

FIG. 4

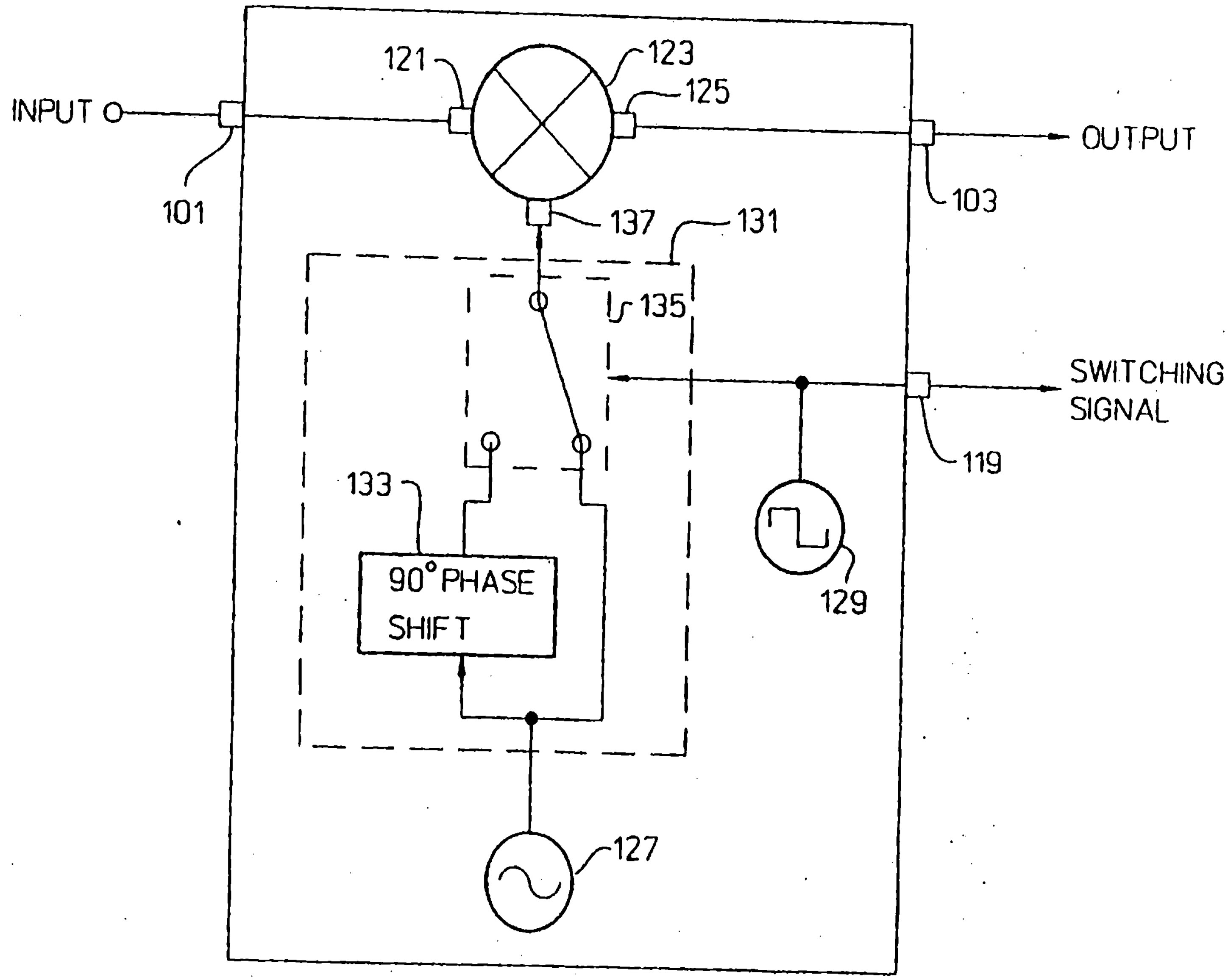

INPUT
101
121
123
125
OUTPUT
103
137
131
135
SWITCHING
SIGNAL
119
133
90° PHASE
SHIFT
129
127

FIG. 5A

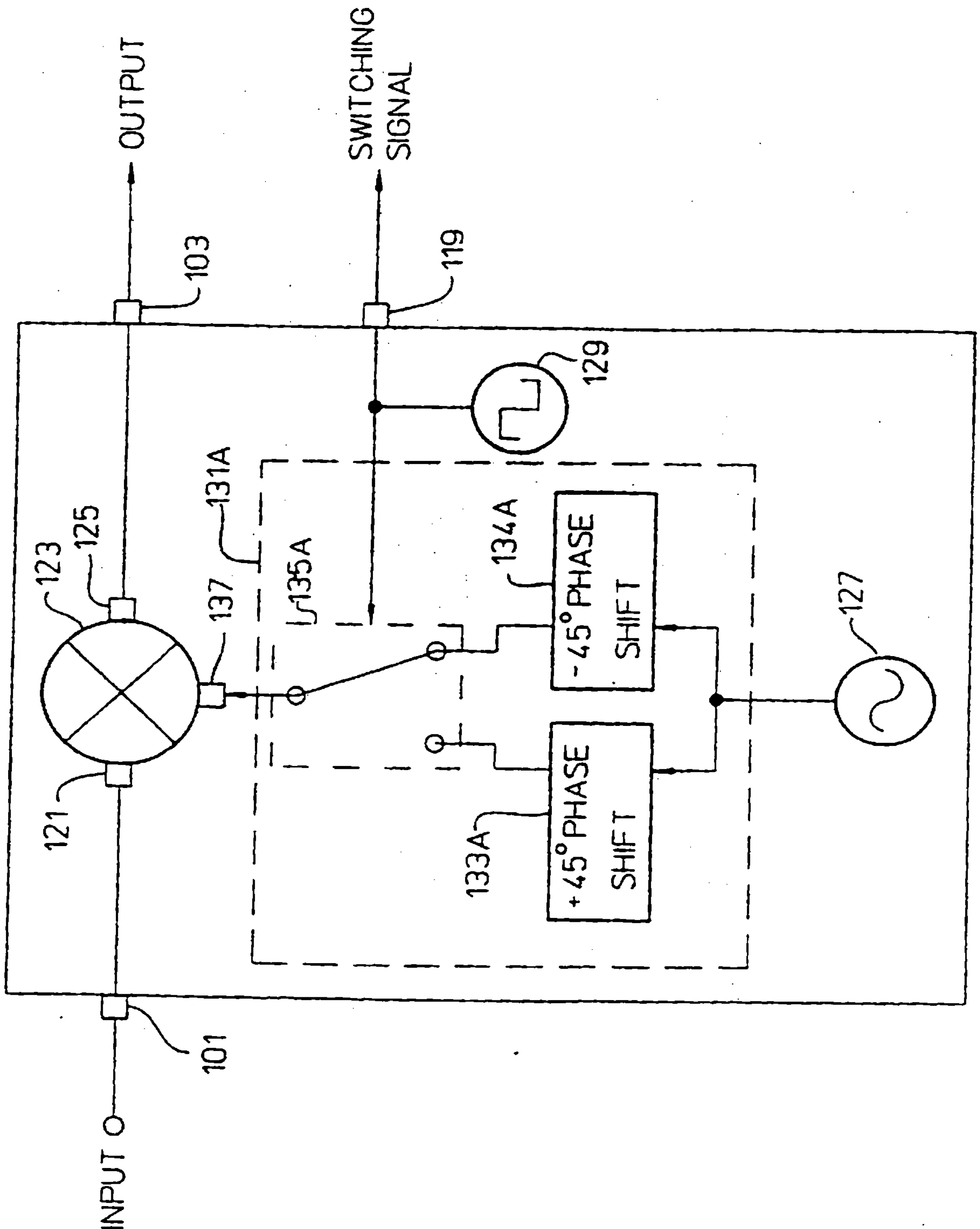

OUTPUT
SWITCHING SIGNAL
103
119
129
131A
135A
134A
123
125
137
121
133A
-45° PHASE SHIFT
+45° PHASE SHIFT
127
101
INPUT

FIG. 5B

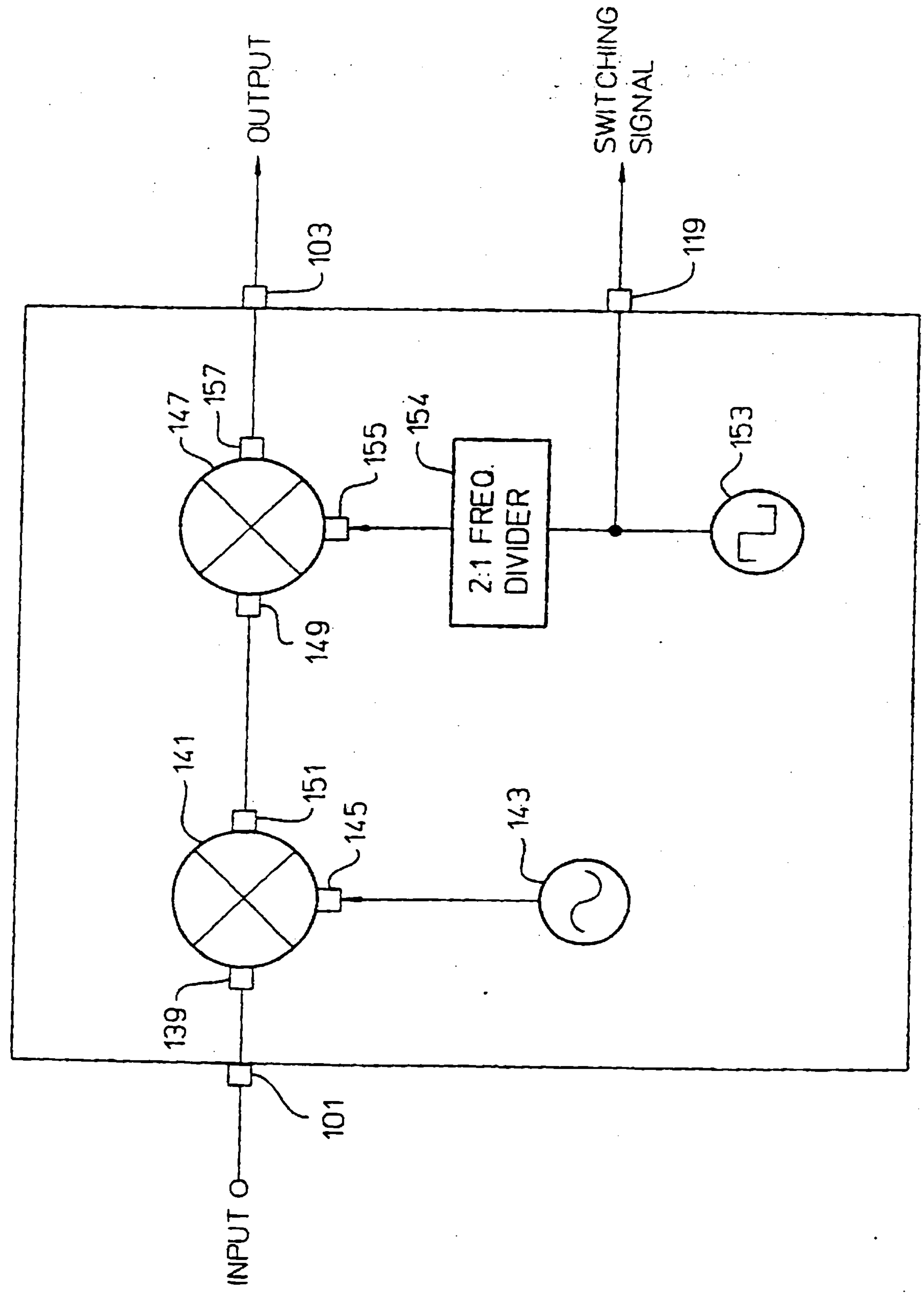

OUTPUT
SWITCHING SIGNAL
103
119
147
157
155
154
2:1 FREQ. DIVIDER
153
149
141
151
145
143
139
101
INPUT

FIG. 6

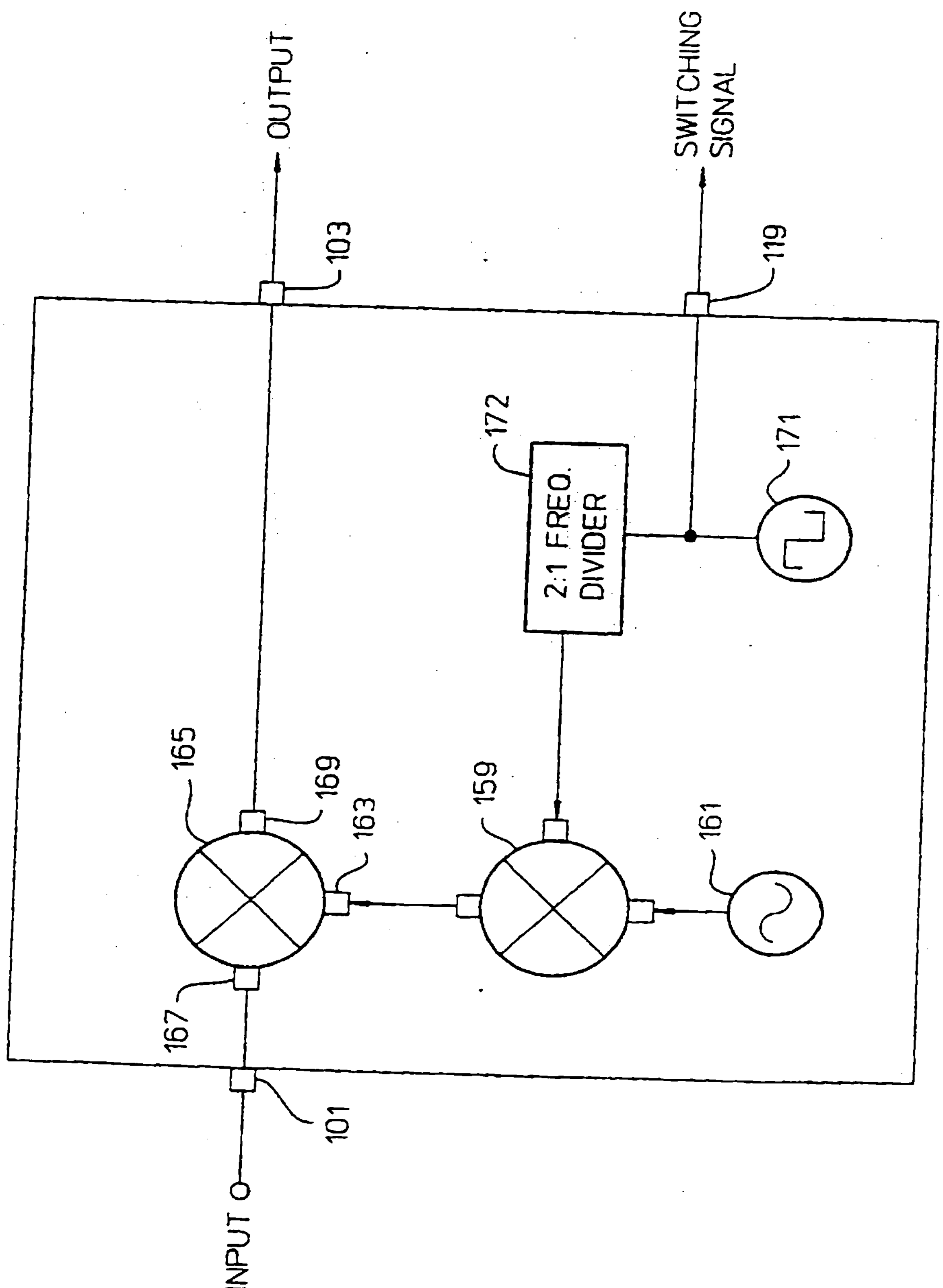

OUTPUT
SWITCHING SIGNAL
103
119
172
2:1 FREQ. DIVIDER
171
165
169
163
159
161
167
101
INPUT

FIG. 7

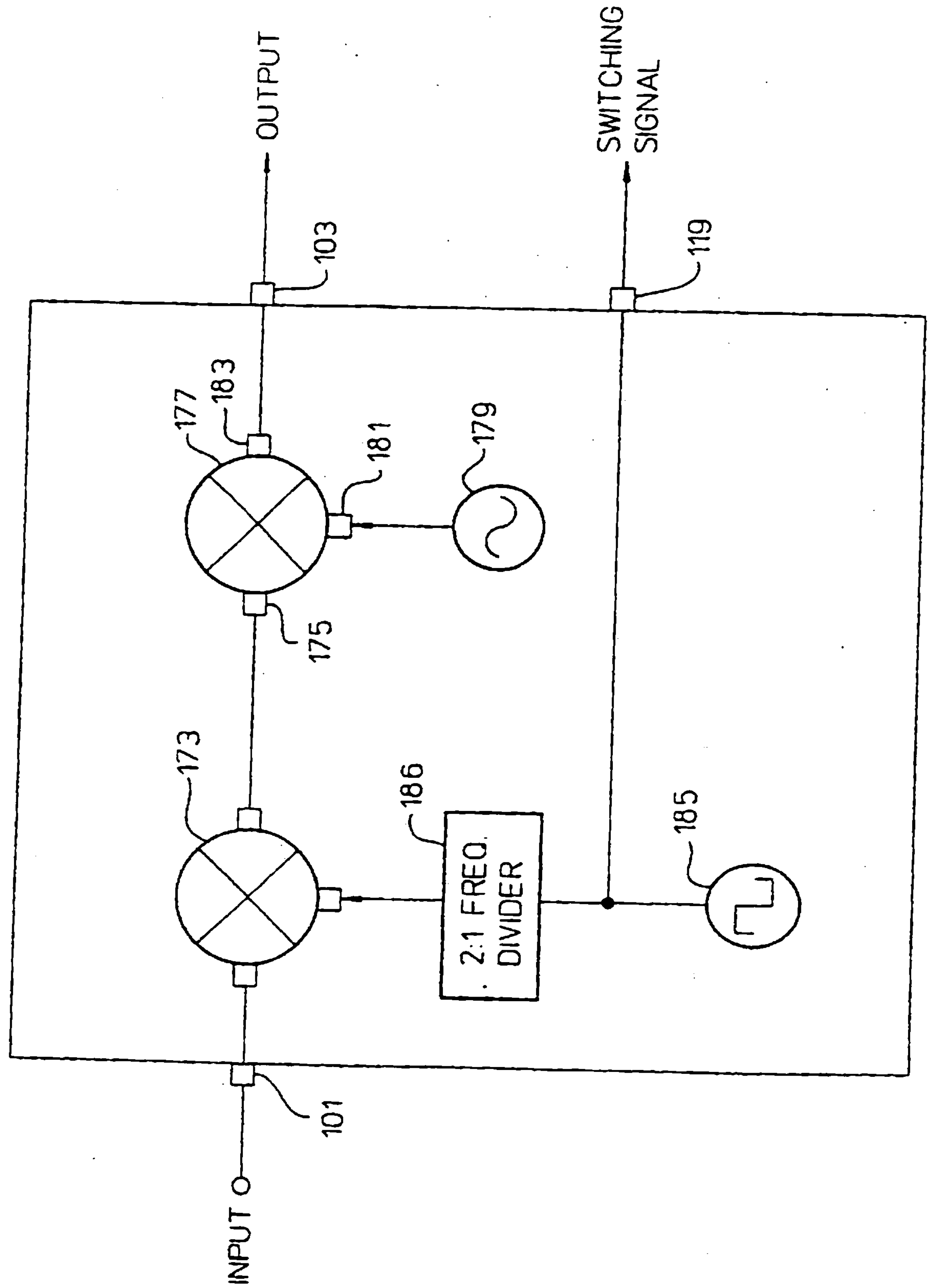

OUTPUT
SWITCHING SIGNAL
103
119
177
183
181
179
175
173
186
2:1 FREQ. DIVIDER
185
101
INPUT

FIG. 8

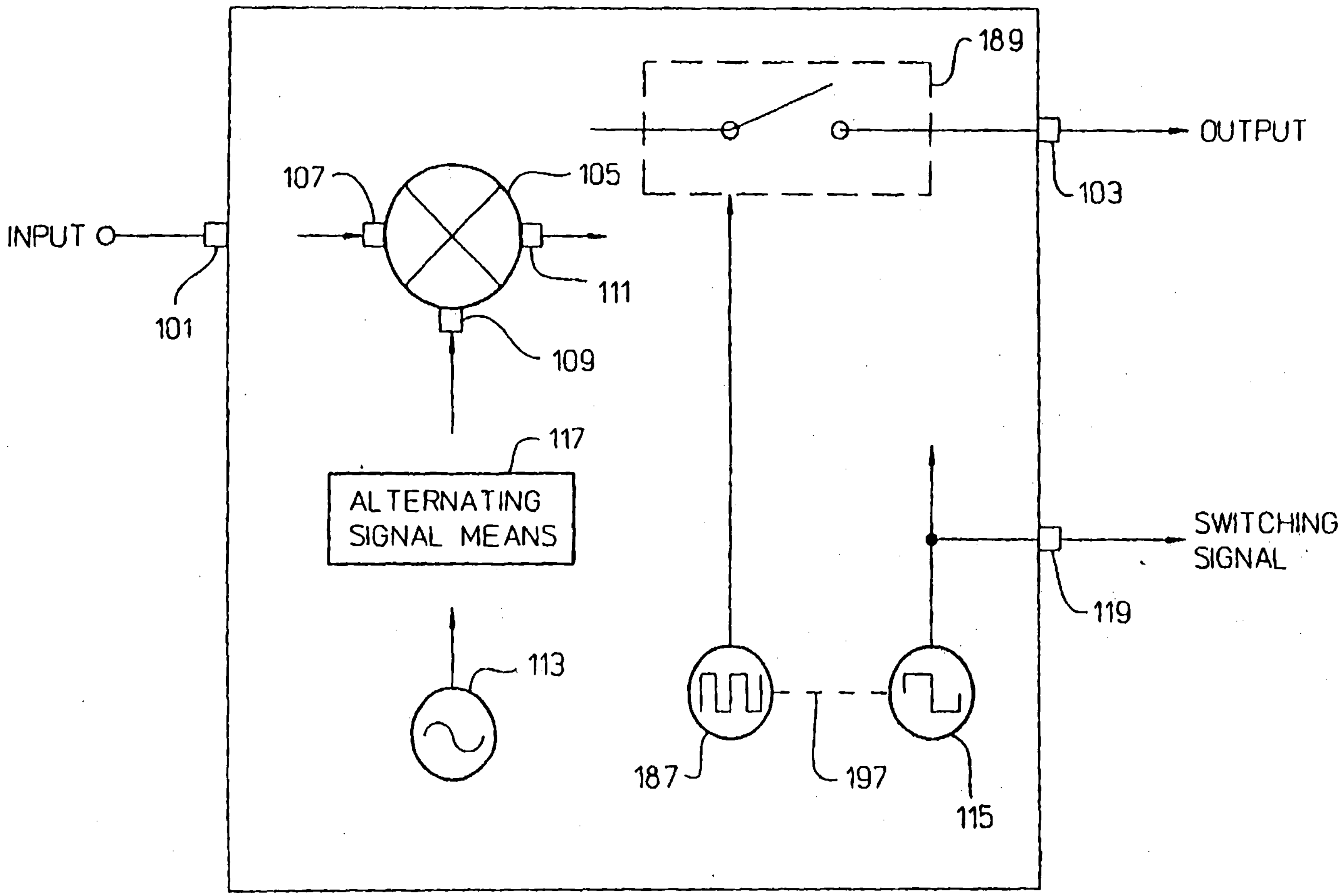

INPUT
101
107
105
111
109
117
ALTERNATING
SIGNAL MEANS
113
189
OUTPUT
103
SWITCHING
SIGNAL
119
187
197
115

FIG. 9

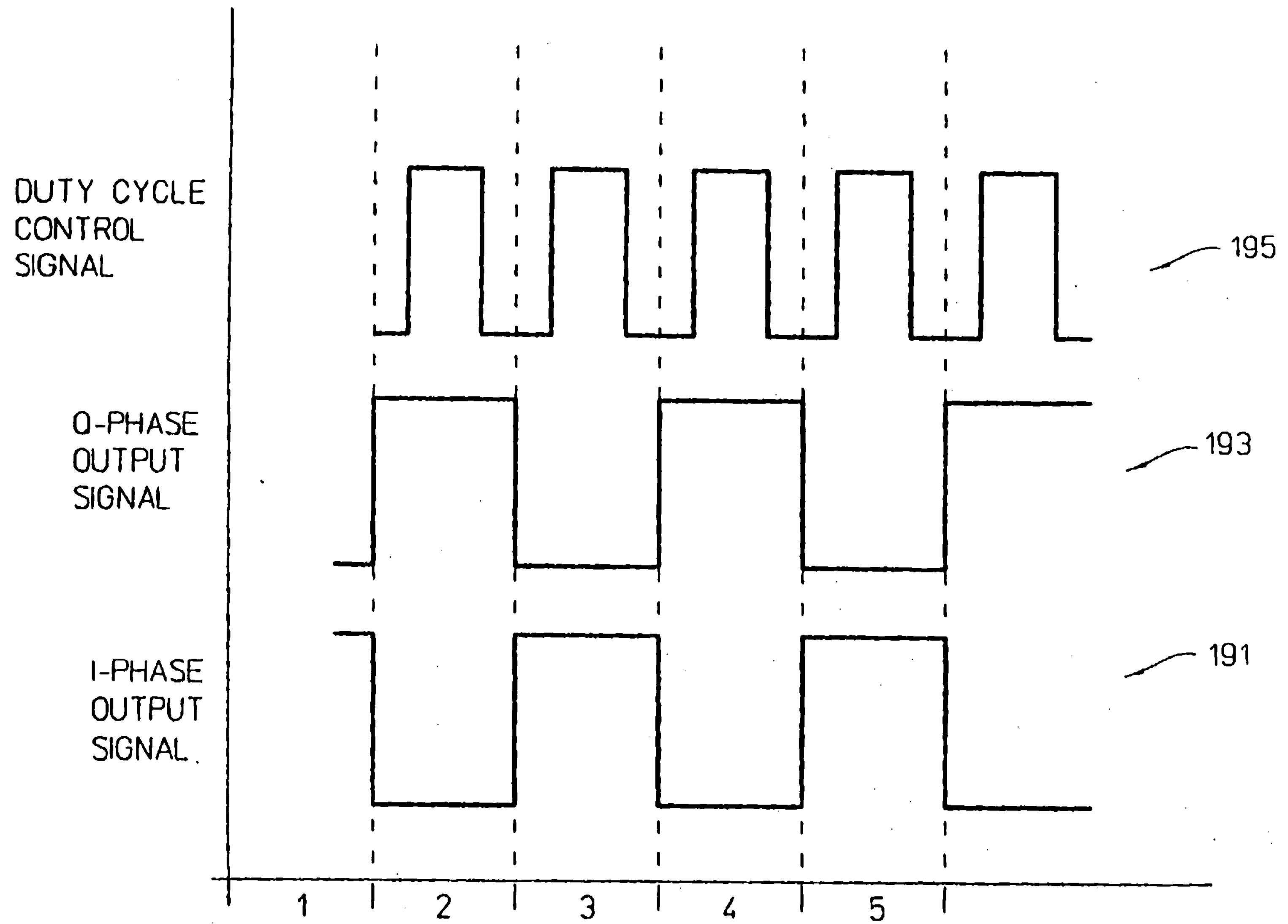
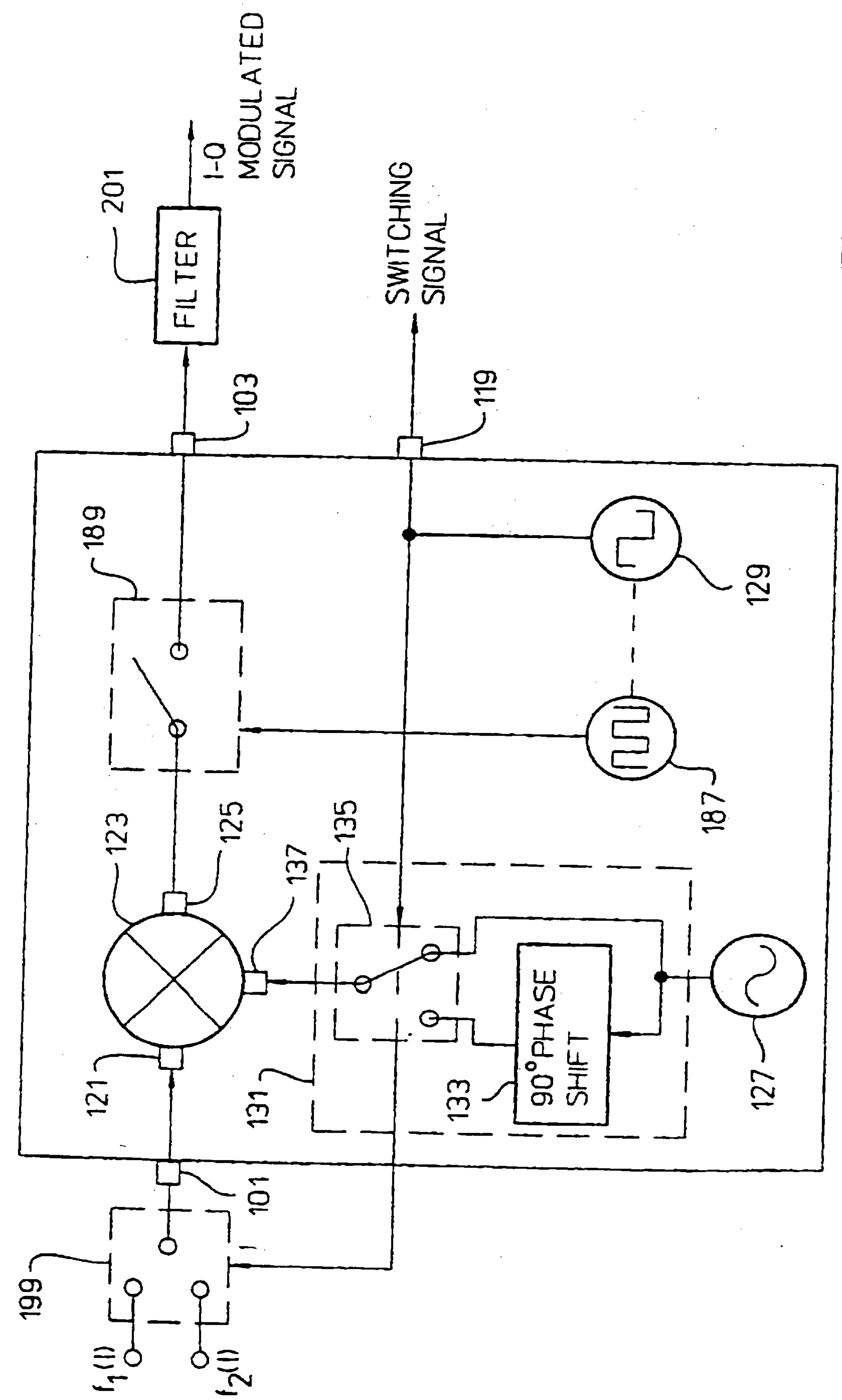
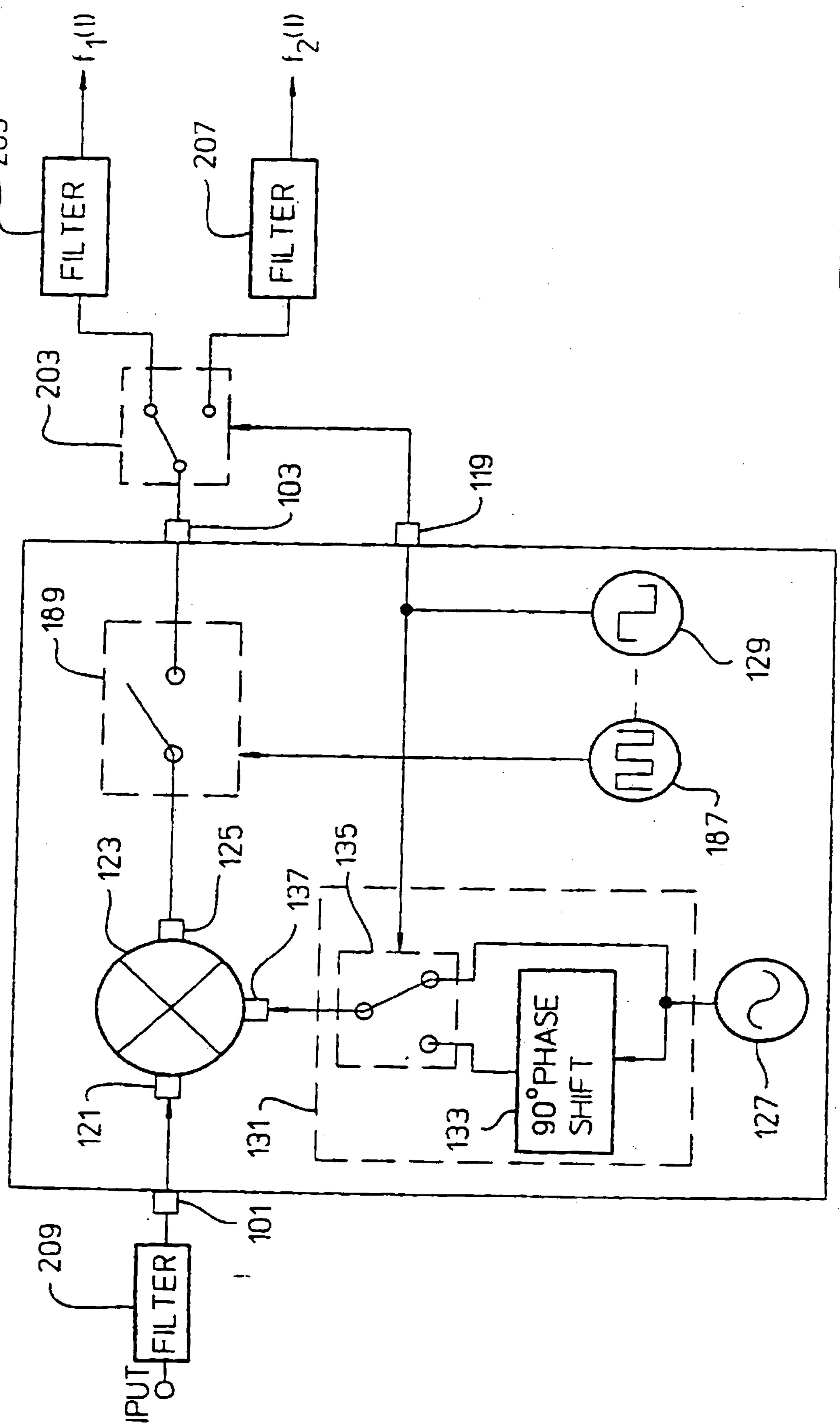

DUTY CYCLE
CONTROL
SIGNAL
Q-PHASE
OUTPUT
SIGNAL
I-PHASE
OUTPUT
SIGNAL
195
193
191
1
2
3
4
5

FIG. 10



I-Q MODULATED SIGNAL
201
FILTER
SWITCHING SIGNAL
103
119
189
129
187
123
125
137
135
90° PHASE SHIFT
121
131
133
127
101
199
$f_1(I)$
$f_2(I)$

FIG. 11



FILTER
FILTER
FILTER
90°PHASE SHIFT
IPUT
f1(t)
f2(t)
205
207
203
103
119
189
129
187
123
125
135
137
121
131
133
127
101
209

FIG. 12

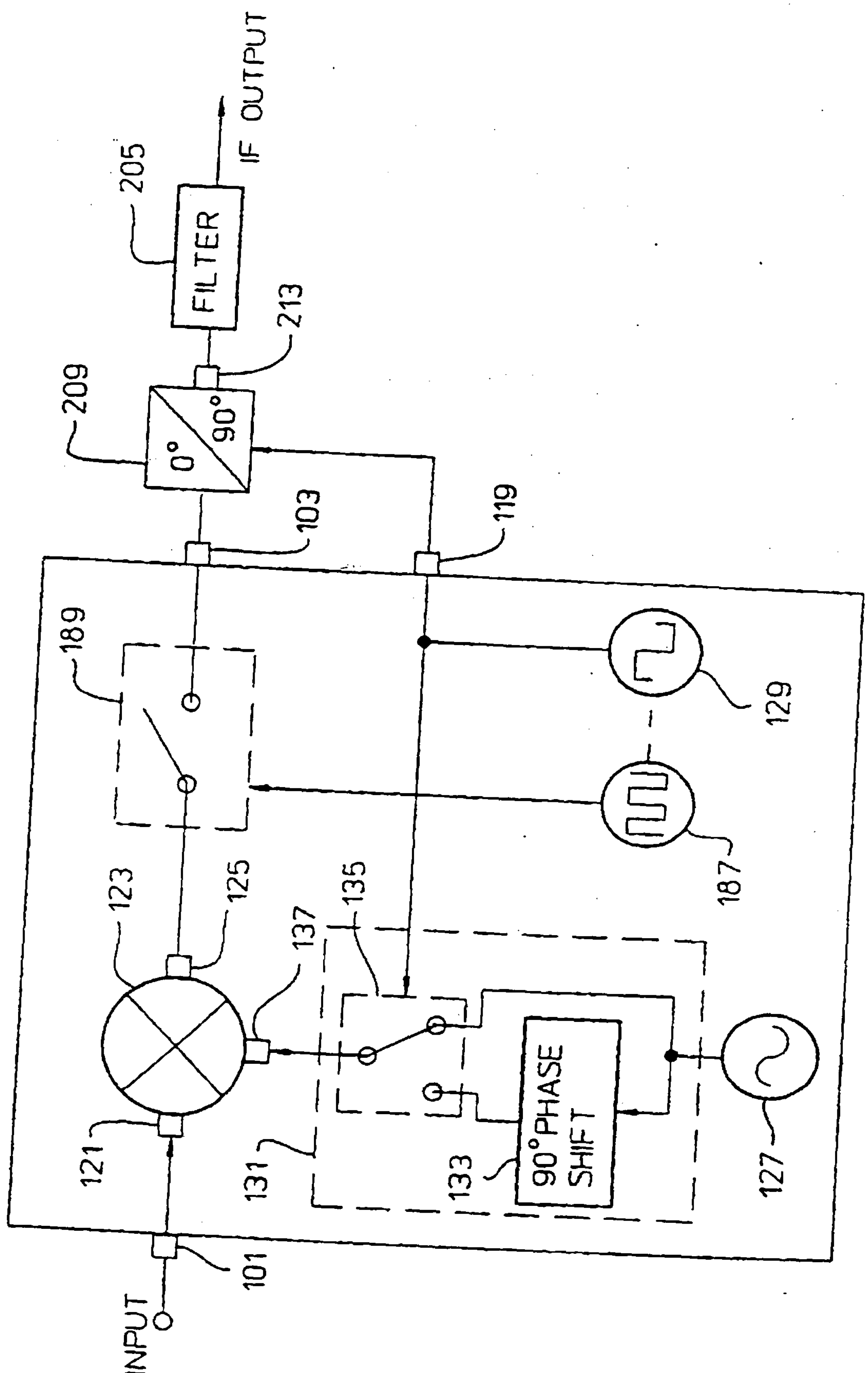

IF OUTPUT
205
FILTER
213
209
0°
90°
103
119
189
129
187
123
125
137
135
121
131
133
90° PHASE SHIFT
127
101
INPUT

FIG. 13

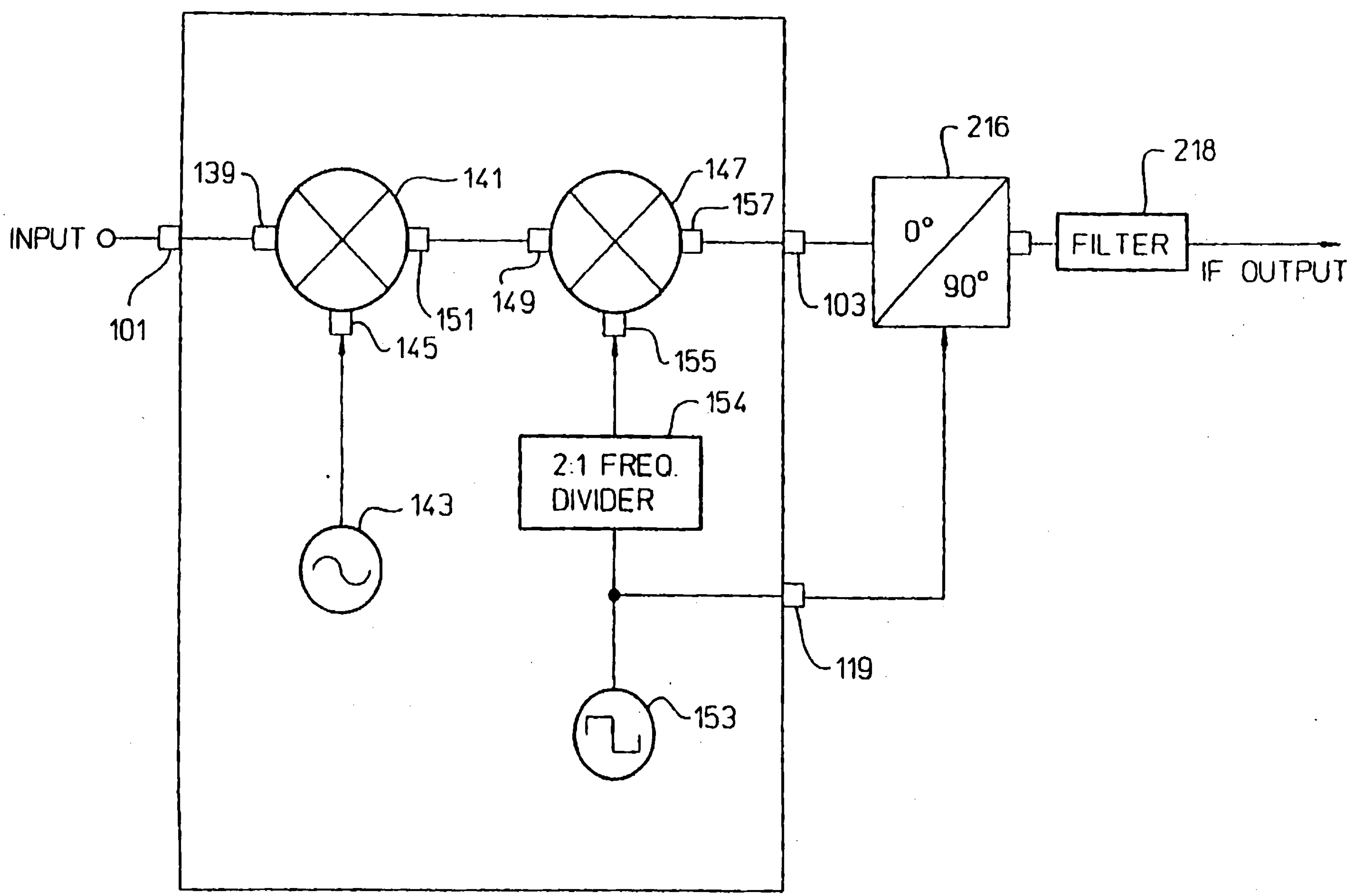

INPUT
101
139
141
145
143
151
149
147
157
155
154
2:1 FREQ. DIVIDER
153
103
119
216
0°
90°
218
FILTER
IF OUTPUT

FIG. 14

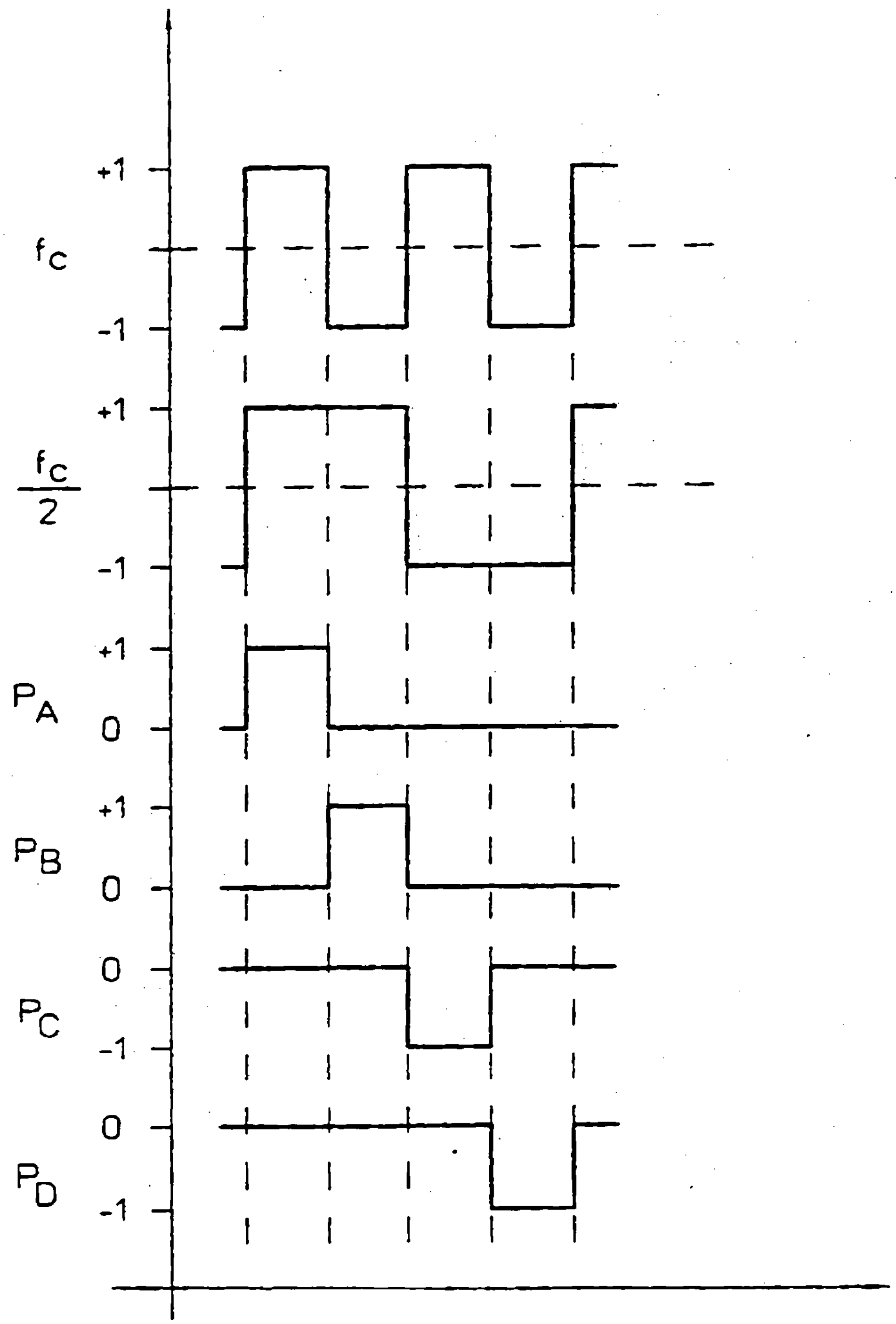


FIG. 15

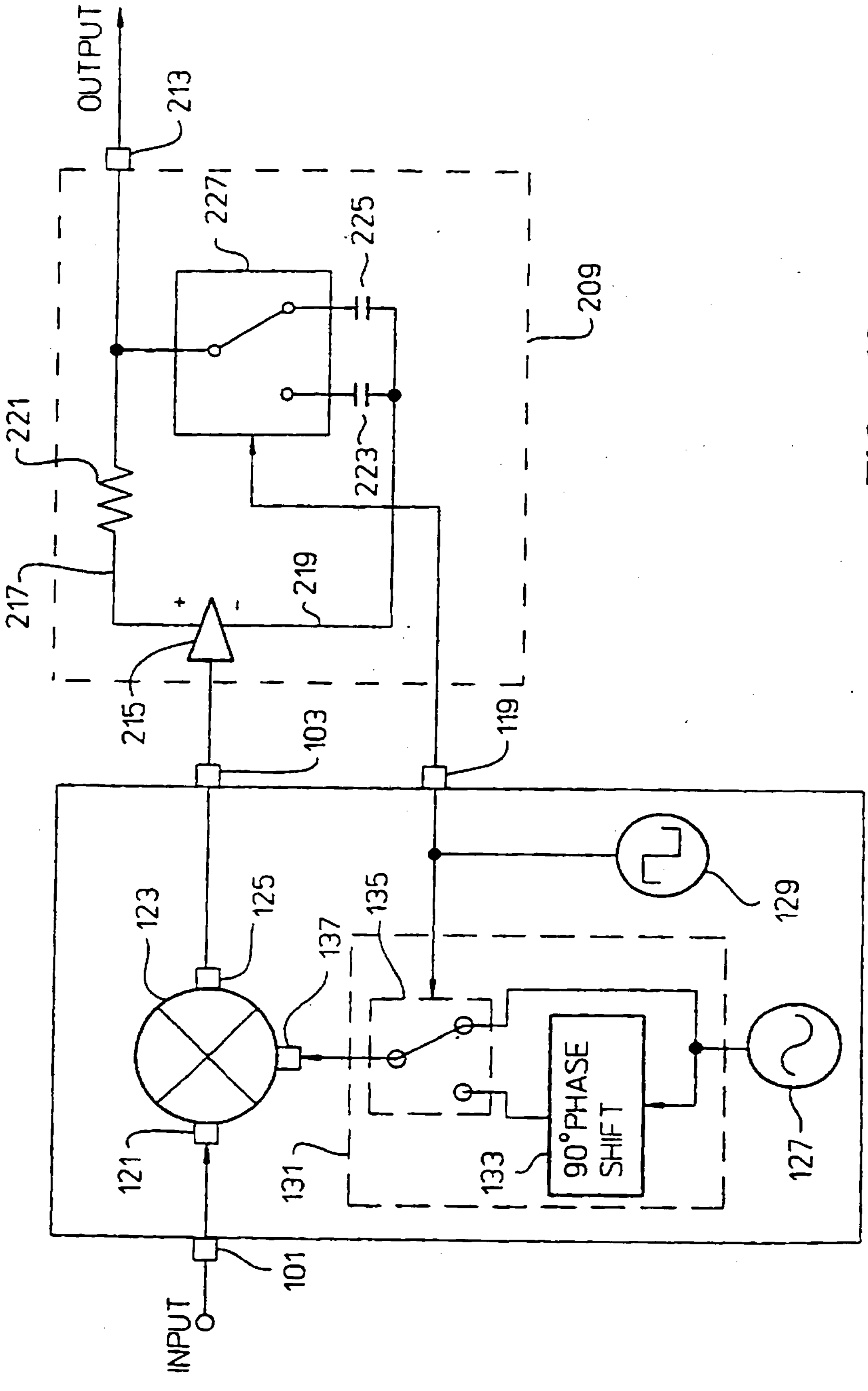

OUTPUT
213
227
225
209
221
223
217
219
215
103
119
123
125
135
137
129
90°PHASE
SHIFT
133
131
121
127
101
INPUT

FIG. 16

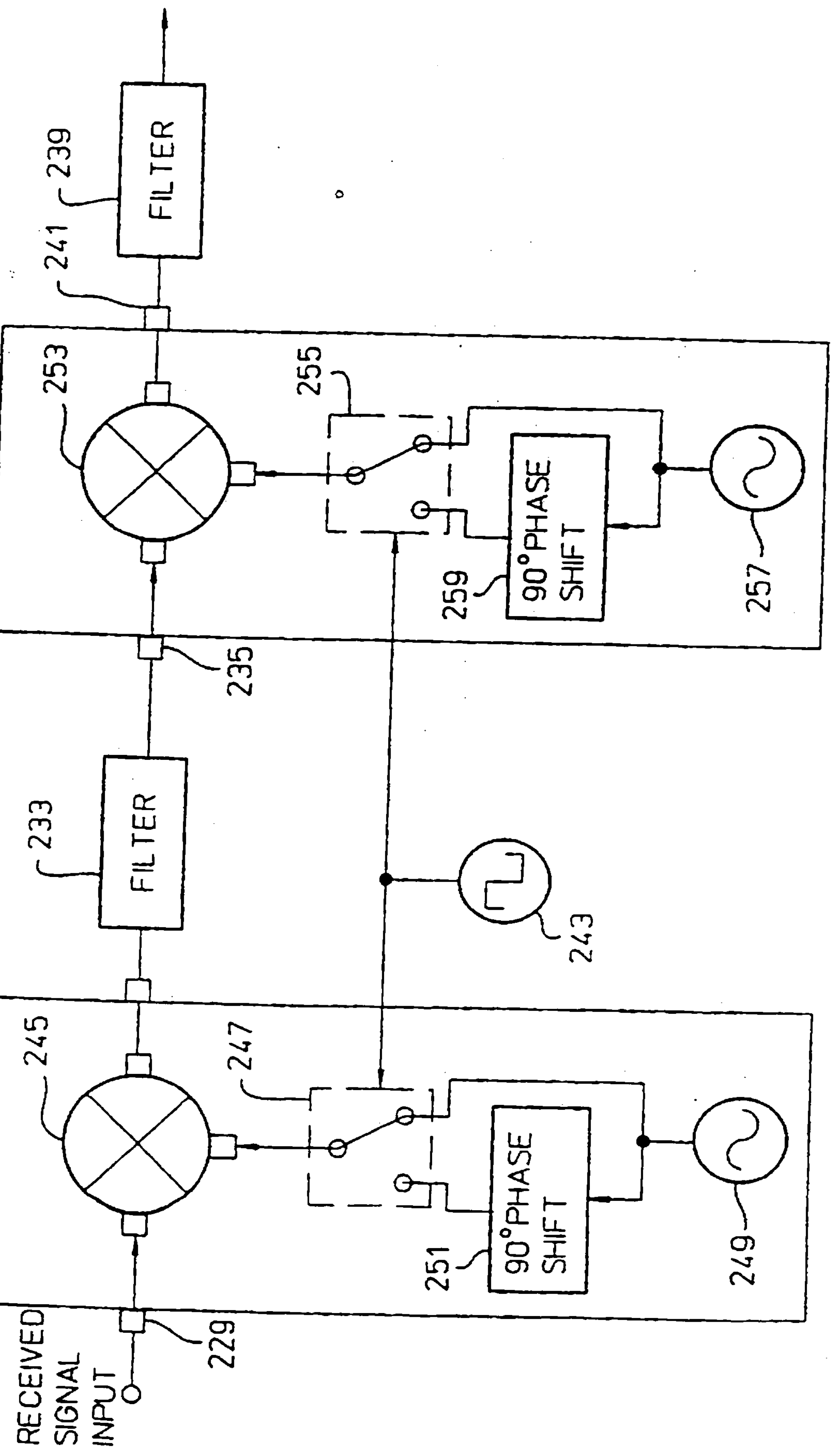

RECEIVED
SIGNAL
INPUT
229
228
245
247
90°PHASE
SHIFT
251
249
FILTER
233
243
235
237
253
255
90°PHASE
SHIFT
259
257
241
FILTER
239

FIG. 17

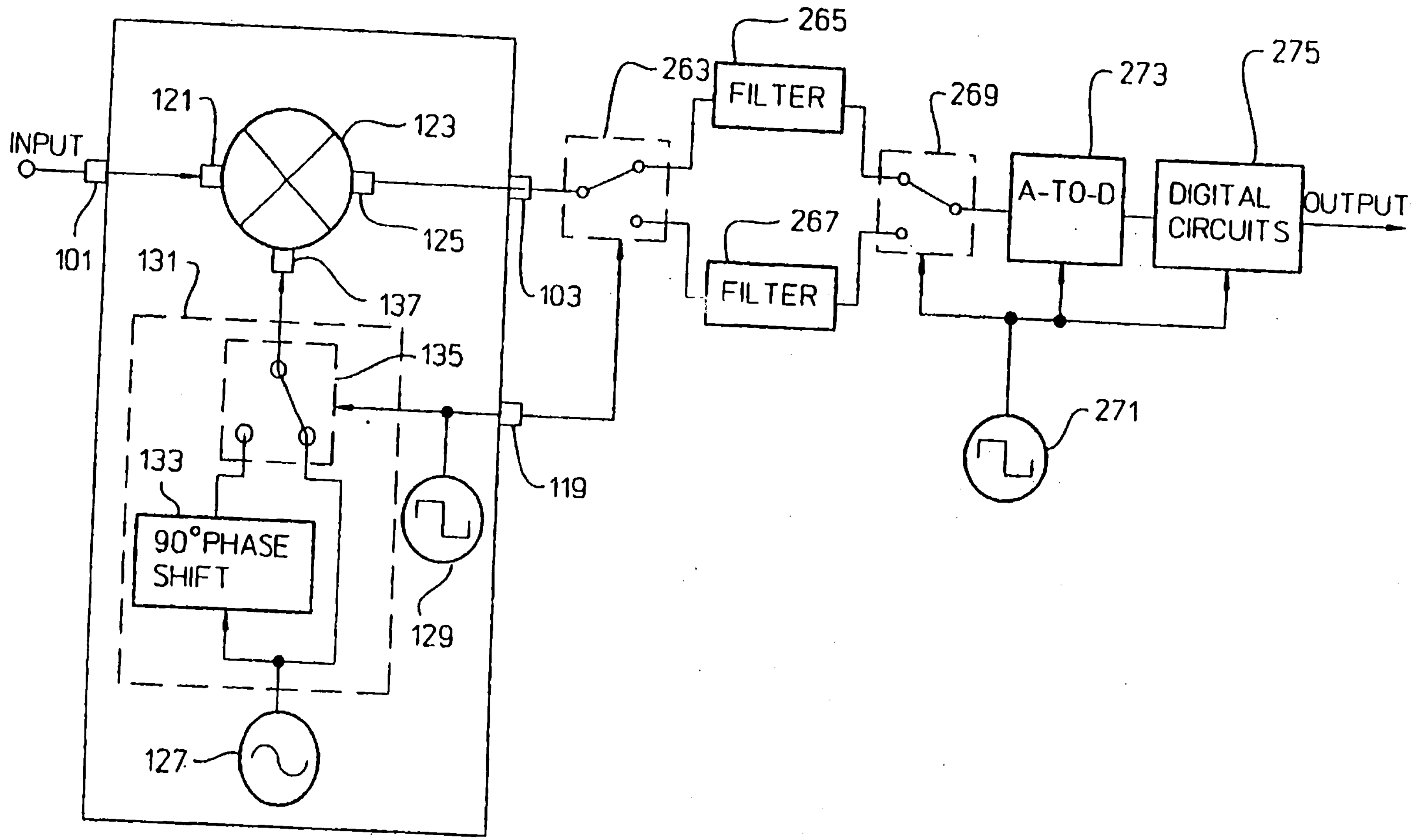
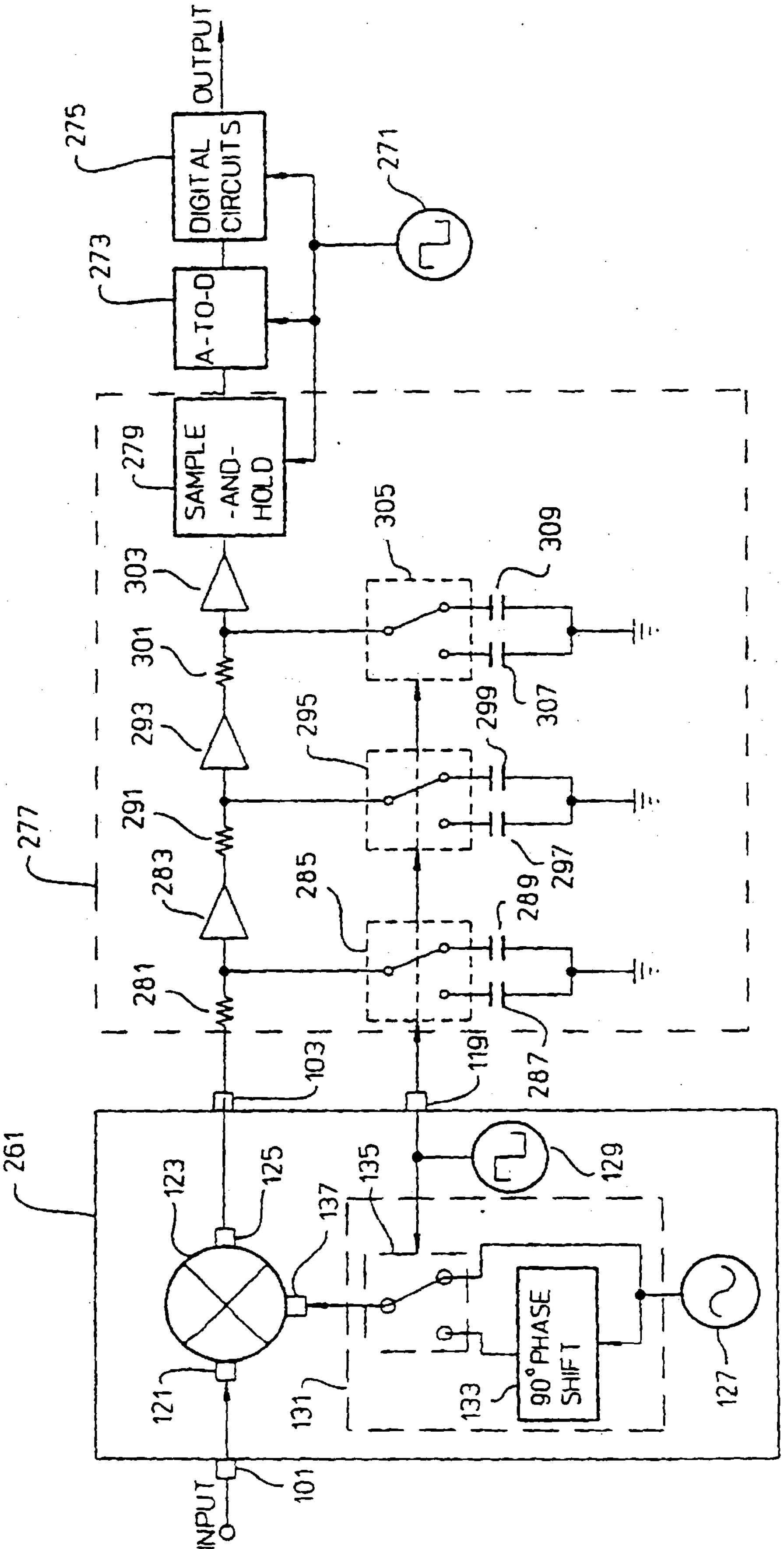

INPUT
101
121
123
125
131
137
135
133
90°PHASE SHIFT
127
129
103
119
263
265
FILTER
267
FILTER
269
273
A-TO-D
275
DIGITAL CIRCUITS
OUTPUT
271

FIG. 18



OUTPUT
275
DIGITAL CIRCUITS
273
A-TO-D
271
279
SAMPLE -AND- HOLD
277
281
283
291
293
301
303
285
295
305
287
289
297
299
307
309
103
119
261
123
125
135
137
129
121
131
133
90° PHASE SHIFT
127
INPUT
101

FIG. 19

2324919

MODULATION AND FREQUENCY CONVERSION BY TIME SHARING

The present invention relates generally to radio communications and more particularly to radio circuitry that uses a time-shared mixer and local oscillator to modulate, demodulate, and change the carrier frequency of an RF signal.

A superheterodyne radio receiver converts the carrier frequency of an input signal to an intermediate frequency while maintaining the modulation (amplitude, phase or frequency modulation) of the input signal. The reason for doing this is that a radio receiver must be able to receive and amplify input signals over a range of carrier frequencies. However, more gain can be obtained from a fixed-frequency amplifier than from one that must amplify over a range of frequencies. Converting the carrier of the input signal to a fixed intermediate frequency allows the amplifier stages to operate on only one frequency, thereby providing more gain from each stage than would otherwise be obtainable. Each such amplifier stage is a bandpass amplifier that amplifies any signal having a frequency within a defined bandwidth centered on the intermediate frequency of the receiver; other signals are rejected.

An ordinary AM or FM receiver of the kind used in the home typically has only one intermediate frequency and a small number of intermediate-frequency ("IF") amplifier stages. However, receivers that operate in the microwave spectrum or beyond may have several IF amplifiers each of which operates at a different intermediate frequency. This is because the total gain required of such a receiver may be as high as 10^5. Several high-gain amplifier stages must be used to obtain such high gain. Operating each stage at a different frequency reduces the danger of amplifier instability due to parasitic feedback from one stage to another.

From the foregoing it will be apparent that every superheterodyne receiver requires a frequency converter to convert the frequency of the input signal to the correct frequency for the IF amplifier. If the receiver has several IF amplifiers operating at different frequencies, then several frequency converters will be required, one for each different intermediate frequency used in the receiver.

A frequency converter has two elements: a local oscillator and a mixer. The local oscillator generates a signal having a frequency (f_{LO}) that differs from the frequency (f_D) of a desired input signal. The mixer combines the desired input signal with the local oscillator signal to produce two new signals, one having a frequency (f_{SUM}) equal to the sum of the desired input signal frequency and the local oscillator frequency:

$$f_{SUM} = f_D + f_{LO} \tag{1}$$

and one having a frequency (f_{DIFF}) equal to the difference between the desired input signal frequency and the local oscillator frequency:

$$f_{DIFF} = f_D - f_{LO} \tag{2}$$

Typically the user adjusts the frequency of the local oscillator below the desired input signal frequency such that, when the local oscillator signal is mixed with the desired input signal, the mixer produces a difference signal having a frequency equal to the IF amplifier frequency (f_{IF}). Substituting f_{IF} for f_{DIFF} and rearranging equation (2) results in the following:

$$f_D = f_{LO} + f_{IF} \tag{3}$$

If other signals are present at the receiver input, they too will be mixed with the local oscillator signal to produce sum and difference signals; in general, however, the frequencies of these sum and difference signals will not be the same as f_{IF} and hence these sum and difference signals will be rejected by the IF amplifier. Thus, only an input signal having a frequency f_D which is equal to the sum of the local oscillator frequency f_{LO} and the intermediate frequency f_{IF} will be converted to the correct intermediate frequency and amplified by the IF amplifier.

In a home radio receiver the local oscillator is tuned by means of the tuning control. Although the dial indicates the frequency of the desired station, the tuning control actually sets the local oscillator frequency to be equal to the difference between the desired frequency and the receiver IF. This is how the desired radio station is selected. In other kinds of receivers, other means may be used to tune the frequency of the local oscillator.

Although most input signals other than the desired one are rejected, one unwanted signal can get through. This is because, as noted above, the mixer produces both sum and difference frequencies. Just as equation (3) shows that an input signal having a frequency equal to the sum of f_{LO} and f_{IF} will be accepted by the IF amplifier, so equation (1) shows that an unwanted input signal having a frequency equal to the difference between f_{LO} and f_{IF} will also be converted to the receiver IF and will be accepted by the IF amplifier. This unwanted signal f_U is referred to as the "image" signal:

$$f_U = f_{LO} - f_{IF} \qquad (4)$$

Subtracting equation (4) from equation (3) shows that the difference between the desired and undesired frequencies is $2f_{IF}$. Most receivers are able to reject such image frequencies by means of a bandpass filter before the mixer. Such a filter prevents the undesired image frequency from entering the mixer. Thus, the mixer only processes the desired signal, since the amplitude of the undesired image signal will have been attenuated by the bandpass filter prior to reaching the mixer.

The input bandpass filter method of image rejection is adequate in receivers such as AM, FM and television receivers of the kind commonly found in the home. This method also gives satisfactory results in the second or further frequency converting stages of a receiver having multiple intermediate frequencies because the desired mixer input frequencies are fixed and are already relatively low. But in the first frequency converting circuit of a receiver tunable across a range of input frequencies in the microwave portion of the spectrum or beyond, the situation is different.

Consider a frequency converting circuit in a receiver designed to operate in a band of frequencies such as one of the industrial, scientific or medical frequency bands having a range of desired input frequencies between, say, 902 MHz and 928 MHz. It would be desirable to use a reasonably inexpensive fixed input bandpass filter to screen out the unwanted image signals. However, to separate a desired input signal having a frequency in this range from its undesired image signal by means of such a filter, there would have to be a guard band of at least 100 MHz between the two range limits. This would require an f_{IF} of at least 63 MHz.

For a monolithic radio receiver (a receiver fabricated on a single integrated circuit substrate) it is advantageous to limit all intermediate frequencies to less than 10 MHz. This is because there are no practical ways to make IF amplifiers that operate at higher frequencies in a monolithic design. Inductor-capacitor-tuned IF amplifiers tunable to frequencies above 10 MHz are difficult to make because low-loss on-chip inductors are not available. The alternative to an inductor-capacitor-tuned IF amplifier would be an active filter. However, an active filter that works at frequencies above 10 MHz demands relatively large amounts of power; this makes it impractical to put both the filter and the rest of the receiver on a single chip. If the filter is located off the receiver chip, an extra port must be provided on the receiver chip to connect the receiver to the filter, and driving the extra parasitic capacitance that accompanies such a port takes still more power. Accordingly the only practical way to design monolithic receivers has been to limit the f_{IF} of the receiver to not more than 10 MHz.

As discussed previously, a receiver intended to receive signals in the 900 MHz range needs an f_{IF} of at least 63 MHz if image frequencies are to be rejected by means of an input bandpass filter. However, a practical receiver with an f_{IF} of over 10 MHz cannot be fabricated on a single substrate. Thus, in order to fabricate a 900 MHz receiver on a single substrate, some other way of rejecting image frequencies must be found.

One kind of frequency converter that includes the capability of rejecting an image signal without using a fixed bandpass filter in front of the mixer is illustrated in FIG. 1. In this prior art system, two matched mixers 11 and 13 are driven in parallel by an input signal. A local oscillator 15 drives the first mixer 11 directly. The local oscillator drives the second mixer 13 through a first 90° phase shifter 17. The first mixer provides an output to a summing circuit 19. The second mixer provides an output to the summing circuit through a second 90° phase shifter 21. The output of the summing circuit becomes the input of an IF amplifier 23. The IF amplifier is tuned to the intermediate frequency f_{IF} of the receiver.

The first mixer passes both the desired signal and the undesired image signal, shifted in frequency from their respective carrier frequencies f_D and f_U to f_{IF}, to the summing circuit. The second mixer does likewise; however, the two phase shifters have the effect of introducing a 180° phase shift into the frequency-converted image signal provided by the second mixer, whereas the phase of the frequency-converted desired signal is unaffected. In the summing circuit, the image signal from the first mixer and the 180° phase-shifted image signal from the second mixer ıncel each other. Thus, only the desired signal is passed from the summing circuit to the IF amplifier.

The action of the two mixers and the two phase shifters will now be explained in more detail. The desired input signal $D(t)$ may be expressed in the form:

$$D(t) = D\sin(\omega_D t + \phi_D) \tag{5}$$

where D is the amplitude of the desired input signal, ω_D is the angular frequency, and ϕ_D is the phase. Applying the definition $\omega=2\pi f$ to equation (3) above results in

$$\omega_D = \omega_{LO} + \omega_{IF} \tag{6}$$

and substituting (6) into (5) yields the following expression for the desired input signal:

$$D(t) = D\sin((\omega_{LO} + \omega_{IF})t + \phi_D) \tag{7}$$

By similar reasoning the unwanted image signal $U(t)$ may be expressed in the form

$$U(t) = U\sin((\omega_{LO} - \omega_{IF})t + \phi_U) \tag{8}$$

The phase angles ϕ_D and ϕ_U are arbitrary and will be disregarded in the rest of this discussion.

The first mixer 11 combines the desired input signal with the local oscillator signal, which may be expressed as $\cos(\omega_{LO}t)$, resulting in the following component in the mixer output signal:

$$D\sin\{(\omega_{LO} + \omega_{IF})t\}\cos(\omega_{LO}t) \tag{9}$$

Applying the trigonometric identity $\sin x \cos y = ½(\sin(x+y) + \sin(x-y))$ to expression (9) yields the following:

$$½D(\sin(2\omega_{LO} + \omega_{IF})t + \sin \omega_{IF}t) \tag{10}$$

The first term of expression (10) has a frequency $(2\omega_{LO} + \omega_{IF})$, a frequency that will be attenuated and ignored by the IF amplifier. Thus, the second term of expression (10) is the only component of the desired signal, after mixing in the first mixer, that will be amplified by the IF amplifier. This second term is expressed as follows:

$$½D\sin\omega_{IF}t \tag{11}$$

By similar reasoning, the only component of the image signal, after mixing in the first mixer, that will be amplified by the bandpass amplifier is:

$$-½U\sin\omega_{IF}t \tag{12}$$

The second mixer 13 combines the desired input signal with the phase-shifted local oscillator signal. The phase-shifted local oscillator signal is expressed as $\sin(\omega_{LO}t)$. Reasoning as before, the desired input signal after mixing in the second mixer has only one component that will be accepted by the IF amplifier:

$$½D\cos\omega_{IF}t \tag{13}$$

which leads expression (11) by 90°. The image signal, after mixing in the second mixer, has only one component that will be accepted by the IF amplifier:

$$\tfrac{1}{2}U\cos\omega_{IF}t \tag{14}$$

which lags expression (12) by 90°. The second phase shifter 18 delays the phase of both expressions (11) and (12) by 90°, resulting in:

$$\tfrac{1}{2}D\sin\omega_{IF}t. \tag{15}$$

for the remaining component of the desired signal and

$$\tfrac{1}{2}U\sin\omega_{IF}t \tag{16}$$

for the remaining component of the image signal. When expressions (11), (12), (15) and (16) are added together in the summing circuit, the sum is

$$D\sin\omega_{IF}t \tag{17}$$

It will be apparent that the amplitudes of the undesired image components in the outputs of the mixers 11 and 13, set forth above as expressions (12) and (16) respectively, must exactly match if the undesired image signal is to be completely eliminated. This requirement is especially critical in mobile applications of a monolithic receiver because the power of an undesired image signal at the receiver antenna may be as much as 60 dB larger than that of a desired signal due to the so-called "near-far" effect. Rejecting an image by more than 60 dB (suppressing it -- even in the worst case -- below the desired signal) requires the difference between the gains of the two mixers to be less than 0.1% and any phase error between the mixers to be less than one milliradian. These tolerances are not achievable in a practical monolithic receiver. State-of-the-art image-rejecting frequency-converting circuits of the kind shown in FIG. 1 have not been capable of attenuating unwanted image signals by more than 20 dB in spite of the superior component matching achievable in integrated circuits.

Attempts to build practical I-Q modulation and demodulation circuits operable at frequencies at or above the 900 MHz range have encountered similar difficulties. Consider an I-Q modulation circuit as shown in FIG. 2. This circuit modulates a single carrier signal with two different signals $f_1(t)$ and $f_2(t)$. The first signal $f_1(t)$ is applied to a signal input of a first mixer 25 and the second signal $f_2(t)$ is applied to a signal input of a second mixer 27. A local oscillator 29 provides a

carrier signal at the desired carrier frequency F_D; this signal is expressed as $\cos\omega_D t$ and is applied to the first mixer which combines its two input signals to provide a signal expressed as $f_1(t)\cos\omega_D t$. The oscillator signal is also applied to a 90° phase shifter 31. The output of the phase shifter, which is expressed as $\sin\omega_D t$, is applied to the second mixer which in turn provides an output expressed as $f_2(t)\sin\omega_D t$. These two mixer output signals are combined in a summer 33 to provide a final output signal $F(t)$ expressed as:

$$F(t) = f_1(t)\cos\omega_D t + f_2(t)\sin\omega_D t \tag{18}$$

An I-Q demodulator is shown in FIG. 3. A signal such as the signal $F(t)$ of equation (18) is applied to the inputs of two mixers 35 and 37. A local oscillator 39 provides a signal at the carrier frequency F_D. This signal, which as before is expressed as $\cos\omega_D t$, is applied to the first mixer 35 which in turn provides an output expressed as:

$$F(t)\cos\omega_D t = f_1(t)\cos^2\omega_D t + f_2(t)\cos\omega_D t\sin\omega_D t \tag{19}$$

Equation (19) by the application of trigonometric identities becomes:

$$F(t)\cos\omega_D t = \tfrac{1}{2}f_1(t) + \tfrac{1}{2}f_1(t)\cos 2\omega_D t + \tfrac{1}{2}f_2(t)\sin 2\omega_D t \tag{20}$$

This output is applied to a low-pass filter 41 which attenuates the 2ω terms. Thus, the filter output is $\tfrac{1}{2}f_1(t)$, which after amplification is simply the original first signal $f_1(t)$.

The oscillator signal is also applied to a 90° phase shifter 43 which provides a signal that is expressed as $\sin\omega_D t$. This signal is applied to the second mixer 37 which in turn provides an output expressed as:

$$F(t)\sin\omega_D t = f_2(t)\sin^2\omega_D t + f_1(t)\cos\omega_D t\sin\omega_D t \tag{21}$$

Equation (19) by the application of trigonometric identities becomes:

$$F(t)\sin\omega_D t = \tfrac{1}{2}f_2(t) + \tfrac{1}{2}f_1(t)\sin 2\omega_D t - \tfrac{1}{2}f_1(t)\cos 2\omega_D t \tag{22}$$

This output is applied to a low-pass filter 45 which, similarly to the filter 43, attenuates the 2ω terms. Thus, the output of the filter 45 is $\tfrac{1}{2}f_2(t)$, which after amplification is simply the original second signal $f_2(t)$.

From this description it will be apparent that the phase shifters 31 (in the modulator) and 43 (in the demodulator) must shift the phase of their respective oscillator signals by exactly 90° to avoid inadvertently mixing up the two signals $f_1(t)$ and $f_2(t)$. It is also necessary that the modulator mixers 25 and 27 be precisely matched and that the demodulator mixers 35 and 37 be precisely matched. In the 900 MHz range, these constraints are difficult to satisfy.

Accordingly, it will be apparent that there is a need for a practical, realizable monolithic frequency conversion circuit that can receive a desired signal, especially at or above the 900 MHz range, and reject an image signal that is as much as 60 dB more powerful than the desired signal. There is also a need for I-Q modulator and demodulator circuits that can give good performance at similar frequencies.

In parent patent application 9520579.5, there is disclosed and claimed a time-share mixer circuit that eliminates the need for precisely matched mixers in frequency conversion and I-Q modulation circuitry at any frequency up to the 900 MHz range and beyond. A frequency converter embodying the principles of the present invention rejects an image signal as much as 60 dB more powerful than a desired signal.

Briefly and in general terms. the time-share mixer circuit includes a mixer with primary and oscillator input ports. a local oscillator that provides an initial oscillator signal, a switching signal source, and alternating signal means driven by the switching signal. The alternating signal means controls the circuit in such a way that the output alternates back and forth between an in-phase output signal and a quadrature-phase output signal. The in-phase output signal is the same as that output signal which the mixer would provide in response to a given input signal if the initial oscillator signal were applied to the oscillator input port. The quadrature-phase output signal is the same

as that output signal which the mixer would provide if the initial oscillator signal were phase-shifted by 90° and then applied to the oscillator input port.

In a first embodiment, the input signal is applied directly to the primary input port of the mixer and the time-share output signal is provided directly at the mixer output port. In this embodiment the alternating signal means consists of a phase shifter that shifts the phase of the initial oscillator signal by 90° and a switching element that alternately couples the initial oscillator signal and the phase-shifted oscillator signal to the oscillator port of the mixer.

In other embodiments, the alternating signal means consists of a clocked inverter in series with one of the ports of the mixer. In one such embodiment the clocked inverter is in series with the oscillator port of the mixer, the primary input port receives the input signal, and the output port provides the output signal. In another embodiment the clocked inverter is connected in series with the mixer output port, and in yet another embodiment the input signal is applied to the primary input port through the clocked inverter. In all of these embodiments, the clocked inverter is switched at a rate one-half the switching rate of the switching element in the first embodiment.

A time-share mixer as described above provides an output signal that switches back and forth at a rapid rate between the in-phase and quadrature phase outputs. In some applications it is desirable to equalize the duty cycles of these two outputs. A duty-cycle equalizer that switches at an even multiple of the rate of the switching signal alternately enables the in-phase and quadrature phase outputs for equal periods of time.

A time-share mixer in combination with an output phase shifter provides a frequency converter that shifts the carrier frequency of a desired RF signal while rejecting unwanted image signals. The output phase shifter, responsive to the switching signal, alternately shifts the phase of the time-share output signal by first and second phase shifts, the second phase shift differing from the first by 90 degrees. The output phase shifter is followed by a filter which provides the desired frequency-shifted signal.

In one embodiment the output phase shifter is a resistor-capacitor ("RC") filter with two switchable capacitors of different values. Switching back and forth between the two capacitors provides the two different phase shifts. In another embodiment the output of the time-share mixer is passed through a plurality of cascaded low-pass RC filters, a sample-and-hold circuit, an analog-to-digital converter, and a digital phase shifter responsive to a switching signal to provide the two different phase shifts. Still another embodiment uses a second time-share mixer as the phase shifter.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

FIGURE 1 is a block diagram of a frequency conversion circuit of a superheterodyne receiver according to the prior art.

FIG. 2 is a block diagram of an I-Q modulator according to the prior art.

FIG. 3 is a block diagram of an I-Q demodulator according to the prior art.

FIG. 4 is a conceptual diagram of a time-share mixer circuit of a frequency converter according to the invention.

FIG. 5A is a block diagram of a time-share mixer circuit that includes a local oscillator phase shifter.

FIG. 5B is similar to FIG. 5A except that two phase shifters are used to generate the initial and phase-shifted local oscillator signals.

FIG. 6 is a block diagram of a time-share mixer circuit that includes a clocked inverter in series with the output port of the mixer.

FIG. 7 is a block diagram of a time-share mixer circuit that includes a clocked inverter in series with the oscillator input port of the mixer.

FIG. 8 is a block diagram of a time-share mixer circuit that includes a clocked inverter in series with the primary input port of the mixer.

FIG. 9 is a conceptual diagram of a time-share mixer circuit similar to that shown in FIG. 4 and also including a duty-cycle equalizer.

FIG. 10 is a timing diagram showing the relation between the switching signal and the signal that controls the duty-cycle equalizer shown in FIG. 9.

FIG. 11 is a block diagram of an I-Q modulator that includes a time-share mixer circuit similar to that shown in FIG. 5A.

FIG. 12 is a block diagram of an I-Q demodulator that includes a time-share mixer circuit similar to that shown in FIG. 5A.

FIG. 13 is a block diagram of a frequency converter that includes a time-share mixer circuit similar to that shown in FIG. 5A.

FIG. 14 is a block diagram of a frequency converter similar to that shown in FIG. 13 but using a clocked inverter time-share mixer similar to that shown in FIG. 6.

FIG. 15 is a timing diagram of the switching signals of the circuit of FIG. 14.

FIG. 16 is a block diagram of a frequency converter similar to that shown in FIG. 13 and illustrating in partial schematic form a particular embodiment of the phase shifter.

FIG. 17 is a block diagram of a frequency converter similar to that shown in FIG. 13 but using a second time-share mixer circuit as the phase shifter.